THE POTENTIAL OF MASS PRODUCTION FOR REDUCING COSTS IN SHELTER CONSTRUCTION

A PRELIMINARY SURVEY

Prepared for:

OFFICE OF CIVIL DEFENSE
DEPARTMENT OF THE ARMY
WASHINGTON, D.C.

CONTRACT OCD-PS-64-201
WORK UNIT 1156A

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STANFORD RESEARCH INSTITUTE

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By: CHARLES D. BIGELOW

SRI Project MU-4949-021

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PREFACE

A study of the possible utility of mass-production techniques for the construction of low-cost shelters is being conducted by Stanford Research Institute for the Office of Civil Defense under Contract No. OCD-PS-64-201.

The overall effort is SRI project 4949-020 under Richard I. Condit. This report gives the results of a preliminary survey (under subcontract 4949-021) of "the state of the art" of mass production in building construction, upon which decisions can be based in planning future research for mass production of shelters.

The research was conducted in Management and Social Systems, Stanford Research Institute. Project leader and principal investigator was Charles D. Bigelow.

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I INTRODUCTION

This analytical and survey task was undertaken at the request of the Shelter Research Division, Office of Civil Defense, because of OCD's interest in the potential of mass-production techniques for generating cost and time savings in a large shelter program. It is part of a larger study of mass production in shelter development.

Many cost- and time-saving alternatives could be explored prior to implementation of a large shelter program; these include relatively rapidly erected, short-lived shelters that would be implemented during a time of high international tension; permanent shelters; tax relief to motivate private construction; federally implemented programs on government property using volunteer labor; and the potential for savings by use of mass-production techniques in shelter construction. Some of these alternatives may be discarded after little study; some appear immediately attractive; and others must be studied at some length before their attractiveness can be evaluated. The use of mass production for generating savings falls into this last category.

Shelters have not been constructed in large numbers in this country; therefore, comprehensive cost data and records of experience for either conventionally constructed or mass-produced shelters are not available. Additionally, complete data on other types of buildings (which have been partially mass-produced) are also lacking, thereby inhibiting the use of such data to predict costs of mass-produced shelters. Finally, there is no generally accepted method for comparing construction costs and times using mass-production versus conventional techniques. Thus, the present conceptual study is needed (1) to provide a format of total costs for various types of buildings, including shelters, so that cost differences for conventional versus mass-production techniques can be evaluated and (2) to evaluate, on a preliminary basis, prospects for savings through the use of mass-production techniques in shelter construction.

Objective

The objective of this task, within the overall study, is to analyze major costs in various building types and to survey the potential for generating savings through mass production in large-scale shelter programs.

Scope

This task was conducted using a broad interpretation of mass production. Thus, potential cost changes have been analyzed, not only for mass-production techniques in construction, but also for management and design activities that are directly associated with the construction processes.

Changes in total costs are analyzed on the basis of a range of costs, since a lack of data prevents a detailed cost measurement. These changes are understood to apply to techniques for construction, rather than to the advantages of one type of shelter structure over another (e.g., family versus community, beehive versus open box). These techniques (both currently employed as well as promising) apply to new construction and to the large-scale development of fallout shelters using locally available materials. No developmental efforts were undertaken.

Management in mass production is restricted to planning and control techniques for deriving the maximum efficiency from personnel and resources in large-scale operations. Management activities outside the scope of this task include risk analyses, volunteer labor motivation, capital acquisition, the acquisition of equipment or materials, etc. These activities (although essential to overall shelter studies) are not directly applicable to cost comparisons between conventional and mass-production techniques in building. Engineering design of specific shelter configurations or equipment is not considered.

Method of Approach

Data from construction of buildings other than shelters were used in evaluating the potential of mass production in a shelter program.

All cost items pertinent to comparisons between mass-production and conventional techniques have been identified. Additional considerations of building and equipment life, salvage values, and expected increases in the cost of labor, material, and equipment are discussed. Cost experiences with these items have been compiled, and costs for different types of buildings are compared to show where costs in shelter construction parallel those for other types of buildings.

A method for placing all the different types of costs on an equivalent basis for comparison has been outlined. An example is presented to illustrate the suggested procedure for total cost comparisons.

A literature survey was made for mass-production techniques and associated cost differences applicable to both types of construction. The emphasis was placed on the more important cost items above that are amenable to reduction by the application of mass-production techniques. On this basis, a preliminary evaluation of the cost savings potential of mass production in shelter construction was made, and an orientation for future research suggested.

II CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDIES

Consideration of mass production requires an analysis of total building costs rather than just the initial financing, design, and construction costs generally considered in conventional construction. Cost changes resulting from the use of mass-production techniques in other types of buildings apply also to shelter construction. The largest potentials for savings are in the replacement of on-site labor (representing about 28 percent of construction costs or about 12 percent of total building costs) with factory-produced components and in the employment of systems design techniques for reducing costs of the structure, heating-ventilating, lighting, and sanitation components.

The construction industry is in the early stages of incorporating mass-production techniques into the building process, and many of the techniques necessary to mass production in building are currently being used. Possible savings in this country in the manufacturing and construction phases alone are about 5 to 15 percent. Overall savings cannot be determined until a larger study, especially of capital investments, management, and research and development costs, generates more exact data. However, successes in Europe indicate a potential reduction of 10 to 20 percent or more insofar as savings in total costs are concerned.

This preliminary study has shown, on a broad basis, that savings are possible for the more important cost items in shelter construction. Therefore, it is appropriate to outline the direction of future analytical research efforts that would determine detailed costs and identify planning requirements for implementing the mass-production techniques in a shelter program.

Additional data, particularly for R&D, systems design, and capital investment costs, are needed to supplement data sources identified in this report. Performance (rather than material-oriented) specifications for shelter are required so that the advantages of systems design and new materials could be fully realized. Finally, data on the availability of labor, materials, manufacturing resources, and on environmental factors affecting construction and desirable rates of construction are needed.

Given this information, a highly desirable contribution to shelter planning could be made. It would be possible, using the planning and programming techniques discussed in this report, to study detailed cost differences in mass production versus conventional construction. Most

important would be a study of interrelationships among the cost items identified in this report.

An analytical model, representing the items and their relationships, could be developed and the impact, on total costs, of changes in one or more of the cost items could be assessed. The analytical model could also be constructed for sensitivity analyses and for determining cost shifts when mass-production techniques are used in one or more specific phases of the building process.

The result of this analysis and planning effort would be a method for orienting the direction of R&D efforts in material, building, and equipment descriptions for maximum cost savings. Both forms and types of shelter having the least total cost and shortest time construction could be described. Finally the study could provide a structure for the management and planning activities necessary to derive the maximum benefits from mass-production techniques.

"An economy study may be defined as a comparison between alternatives in which the <u>differences</u> between the alternatives are expressed insofar as practicable in money terms."[1]

III ALLOCATION OF TOTAL COSTS

It is necessary in discussing costs for mass-produced buildings to consider costs other than those usually associated with conventional construction; these include design, legal expenses, the main contract, fees, and taxes. Some of the more obvious additional considerations include capital investment in manufacturing plants if needed, changes in project management procedures, and changes in methods of both the architectural and engineering design. Less obvious, perhaps, are changes in costs for financing, maintenance, and insurance. The consequence to this study is that all items in the total cost of a facility must be divided into two groups: those affected by mass production and those not affected. After this division is made, the study emphasis c ' 'on be placed on the costs of those items affected by mass production.

As suggested in a study of housing,[2] the overall cost for private ownership of most building types can be divided approximately as follows:

1/3 -- Cost of land and construction

1/3 -- Cost of money and management

1/3 -- Cost of maintenance, utility services, taxes and fees, and insurance

These costs change somewhat for government ownership, but not enough to change the picture radically.

These items are further subdivided in Table 1. The grouping in the table is arbitrary, but the items are discussed in this general order throughout the report. The following discussion identifies those items that would be affected by mass production and presents data for each that are necessary to a calculation of costs.

1. E. L. Grant and W. G. Ireson, <u>Principles of Engineering Economy</u>, Ronald Press Co., New York, 1960, p. 3.
2. W. K. Wittausch, "New Concepts for the Housing Industry," <u>SRI Journal</u>, January 1965.

Table 1

BUILDING COST ITEMS

Group	Cost Items
Administrative	Planning management Management for operation Financing Legal, fees, etc. Overhead
Design	Architectural design Engineering design
Site acquisition	Land Fees
Construction	Excavation Foundation and building Heating equipment Lighting equipment Sanitary equipment Other building requirements Overhead, profit, and contingencies
Maintenance and/or operation	Maintenance personnel Supplies and equipment Utilities and other Fire and liability insurance Taxes
Additional considerations	Useful life of buildings and equipment Salvage values Future increases in labor, material, and equipment costs

Cost Experience

Administrative

The effects of mass production on administrative items can be illustrated for planning and operating management and for financing costs. Legal expenses, fees, and administrative overhead, however, would require a detailed study and are unlikely to affect the choice between two construction techniques.

Planning and Operations Management.[1] New or unfamiliar techniques in management activities[2] could result in increased costs over those experienced in conventional construction. New types of personnel are needed, and increased responsibilities are placed on the management team, but records of costs for these and for overall management activities are generally proprietary. For purposes of estimating these costs in conventional construction, the experience for a large construction project is used.[3] This experience indicates that project planning, development, and supervision plus legal costs can amount to about 2 percent of total construction costs.

Financing. It is likely that initiation of a nationwide building program would result in indebtedness for a portion or all of the program costs. If this were the case, financing costs would be affected by mass production because of high initial capital investments for new manufacturing facilities not required in conventional construction.

Interest rates, regardless of the construction technique, vary continually over time and according to many different factors. Rates for

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1. Planning and operations management is used to define those activities necessary to the conception, design, and management of the project, both before construction contracts are let and for the building life after the completed facility has been turned over by the contractor. It does not include the contractor's management activities during construction.
2. Lockheed Missiles and Space Co., Cost Estimating for Research, Development, and Information Processing Programs, 1963.
3. Ezra Ehrenkrantz, Project Architect, School Construction Systems Development, Palo Alto, California, anticipates that final overall planning, development, and supervision costs will be about $500,000 for $25 to $30 million of construction costs. This project (for intermittent construction of schools scattered throughout 13 school districts) could be used as a pattern for a regional shelter program.

construction borrowing, however, have remained fairly constant since 1960. Standard and Poor data show median rates of 3.2 percent on long-term, high-grade municipal bonds and 4.2 percent on AAA grade industrial bonds.[1] Federal Reserve Board data on short-term business loans show rates around 5.0 percent[1] over the same period, but a substantial variation across the country.

Architectural and Engineering Design

Both architectural and engineering design costs would be affected by mass production. Cost experience for these items is readily available for either the separate functions or together. Generally an architectural design fee will include that for engineering design as well as for construction supervision. Based on a percentage of the construction costs, the architect's fee[2,3] can range from about 6 percent for repetitive-type warehouses and factories, to 7 percent for apartments and multiple dwellings, to 15 percent for projects involving detailed design such as for built-in furniture and equipment.

Site Acquisition

It is unlikely that costs for the building site would be affected by consideration of mass-production techniques.

Construction

Overhead, profit, contingencies, and miscellaneous items could be expected to remain about the same, regardless of the construction technique used.

There are many ways of combining the other construction costs for comparison, but the combinations are unimportant as long as all related costs are considered. Those presented here are labor, material, equipment, etc.; the division of labor costs between the various construction tasks; and costs in the various construction phases.

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1. Engineering News-Record, Sept. 17, 1964, p. 102.
2. California Council of the American Institute of Architects, Services of the Architect and Recommended Minimum Compensation, San Francisco, California, 1957.
3. H. E. Pulver, Construction Estimates and Costs, 3rd ed., McGraw-Hill, 1960.

Labor, Material, Equipment, etc. This division is intended to show how much of the construction dollar is allocated to labor, and to illustrate those tasks that should be considered for cost reduction through the use of labor-saving machine processes or techniques.

Figure 1 shows a percentage breakdown of the construction dollar for five widely differing types of facilities. The important point to note is that, regardless of the type of facility, from public works dams to schools, the percentages of cost allocated to labor and material are reasonably constant. The largest divergence is in the overhead in single family housing and in the equipment depreciation in the heavy construction of dams.

The Bureau of Labor Statistics has reported on the labor-material division for the "last manufacturing stage" and for on-site construction. Only the labor-material divisions in earlier manufacturing stages (a minor cost component) are lacking.

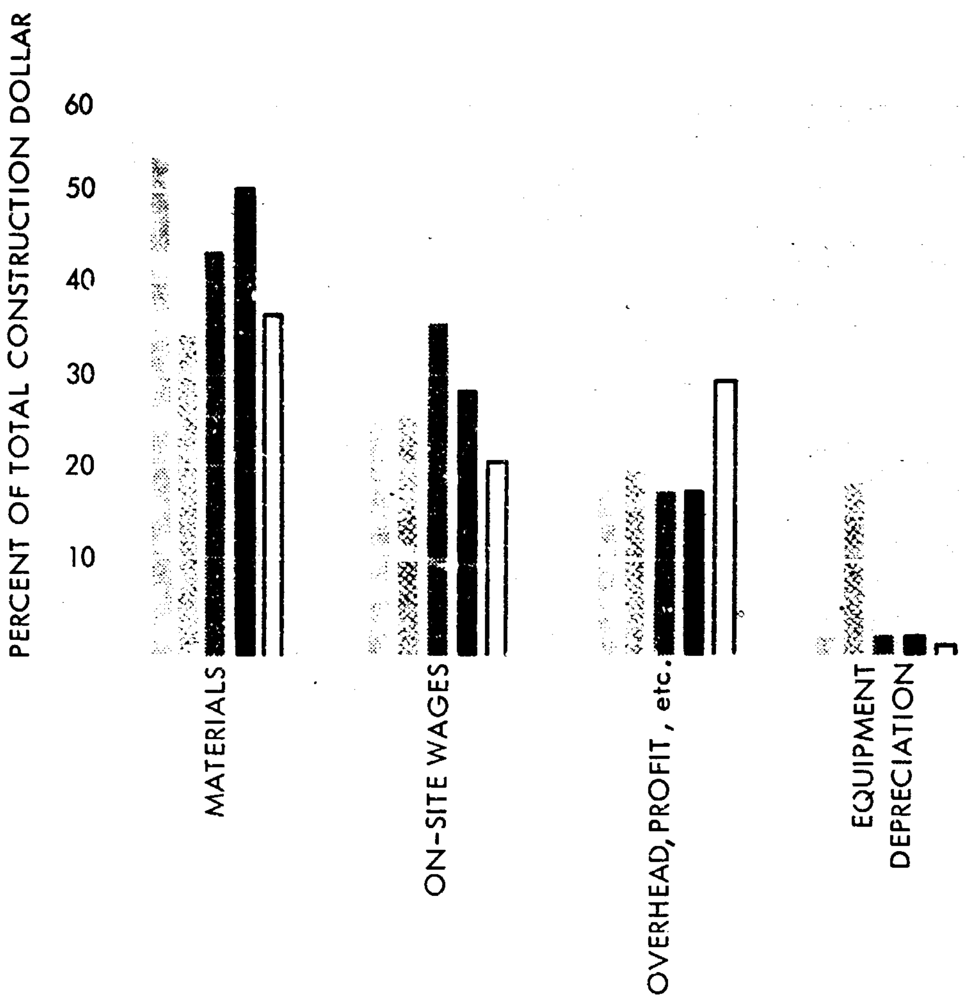
Figure 2 shows the total man-hour requirements per $1,000 of the construction contract for labor from the last manufacturing stage through final construction. These data were compiled for the same types of facilities as in Figure 1.

Labor requirements for the five types of facilities show little variation; therefore the construction phases in which labor savings are most likely to be accomplished can be predicted with a high degree of certainty. Additionally, the division of labor requirements shown in Figure 2 permits the following generalizations. For example, large labor savings in the "Off-Site Construction" activities are unlikely since the products of this stage have probably already been mass-produced to some degree. Meaningful savings in the "Other" activities are improbable due to the small effort expended. Similarly, large labor savings in "Transportation, Trade, and Services" would be difficult to generate since, individually, they are small tasks not generally subject to consolidation or elimination. Thus, "On-Site Construction" and "Manufacturing," representing from 70 to 80 percent of the labor requirements in construction, are shown to be the activities of greatest interest for potential savings through mass production.

Although costs in the manufacturing stage would rise, overall savings would probably accrue from systematizing and standardizing mass-produced components. These savings are discussed in Section IV. Cost savings in on-site construction would result from a number of changes: use of more labor-saving equipment, manufacture of a larger portion or all of the final product, and an elimination of tasks through the employment of new materials or techniques. Actual experience of progress in each of these areas is given in Section IV.

Figure 1

COST ALLOCATION OF THE
ON-SITE CONSTRUCTION DOLLAR

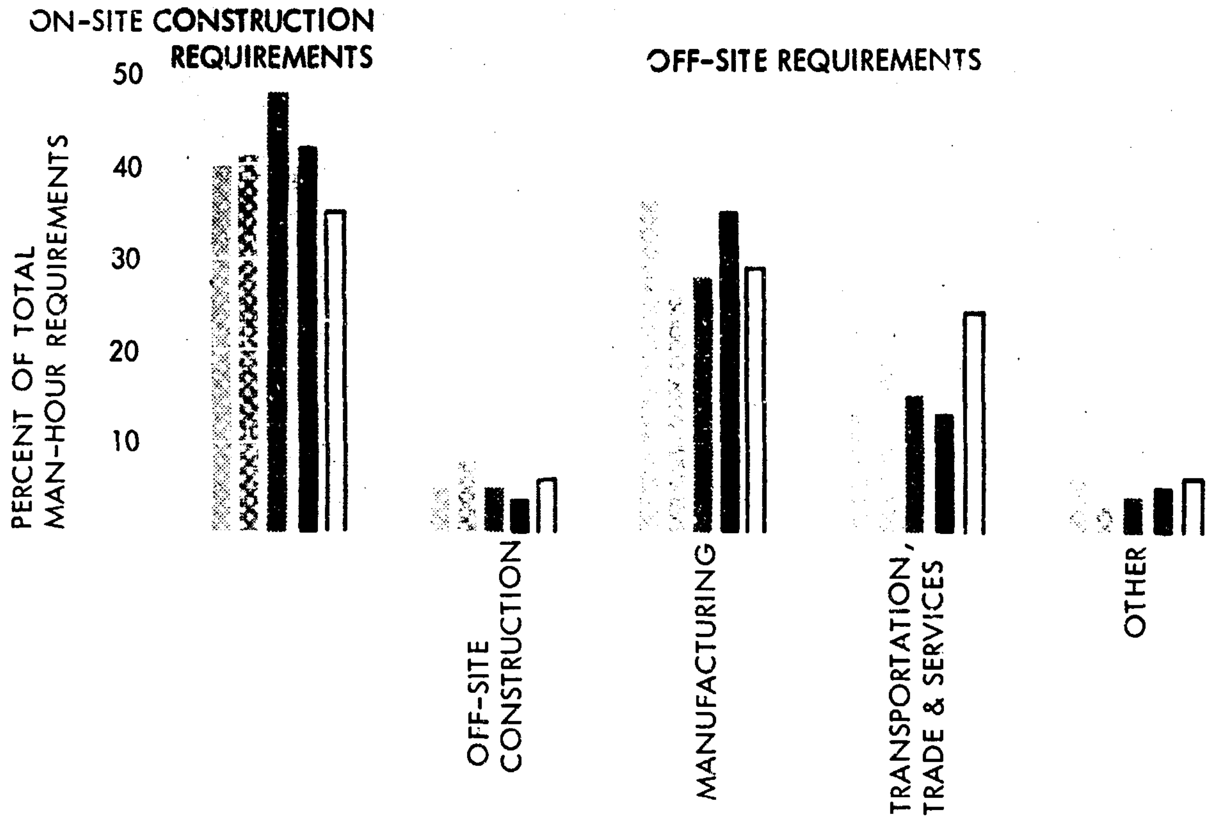


SCHOOLS
PUBLIC WORKS - Dams, Locks, etc.
PUBLIC HOUSING
OFFICE BUILDINGS
HOUSES - SINGLE FAMILY

SOURCE: Bureau of Labor Statistics, Labor and Material Requirements Bulletins (Nos. 1299, 1331, 1390, 1402, 1404), Washington, D. C.

Figure 2

MAN-HOUR REQUIREMENTS PER $1,000 IN CONSTRUCTION CONTRACT



TOTAL MAN-HOUR REQUIREMENTS PER $1000 OF CONSTRUCTION	
212	SCHOOLS
208	PUBLIC WORKS - Dams, Locks, etc.
236	PUBLIC HOUSING
227	OFFICE BUILDINGS
204	HOUSES - SINGLE FAMILY

SOURCE: Bureau of Labor Statistics, Labor and Material Requirements Bulletins (Nos. 1299, 1331, 1390, 1402, 1404), Washington, D. C.

Construction Tasks. The allocation of the total construction dollar, particularly for areas where meaningful labor savings might be possible, can be determined from a division of labor between the various construction tasks. Cost experience during 1964 for some of the facilities shown in Figures 1 and 2 are presented in Table 2. These data are based on scattered information for quite different facilities, but show a consistency in costs for the same construction task. This consistency makes possible an evaluation of those construction tasks in a number of types of facilities that should be investigated first for amenability to mass-production techniques.

The first cost shown in Table 2 is excavation; it will be noted that the two buildings with basements had no higher than average costs for excavation. (See the columns headed "Office Buildings, Maryland" and "Dormitories and Schools, Concrete Frame, California.") Excavation costs for the multistory structures in Table 2 are also at or around the average, indicating that soil conditions often have a greater effect on costs than does excavation itself. The implication for similar soil conditions is that excavation costs for shelters often can be avoided entirely simply by adding the shelter to plans for new construction.[1]

Table 2 shows the more costly items to be the building shell at about 30 percent; interior walls, 15 percent; and heating, electrical, and plumbing, 12, 10, and 8 percent,[2] respectively. On this basis, prospects for the larger savings appear to be in the:

1. Building shell
2. Interior walls
3. Heating and ventilating components
4. Electrical components
5. Plumbing components

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1. See RECON Inc., The Use of Explosives in a Fallout Shelter Building Program, Tallahassee, Florida, 1963. Also, De Leuw, Cather & Co., Deep Excavation Techniques for Shelters in Urban Areas, Chicago, Ill., July 1963.
2. These three percentages for office, school, and apartment construction are some of the smaller percentages for similar components in all types of buildings. See Engineering News-Record, June 18, 1964, p. 120.

Table 2

COST ITEMS IN CONSTRUCTION DURING 1964

Building Type	Office Buildings				Dormitories and Schools				Apartments			
Frame	Steel[a]	Steel[a]	Steel[a]	Steel[a]	Concrete[b]	Concrete[b]	Steel[b]	Steel[b]	Concrete[b]	Concrete[c]	Concrete[c]	Concrete[c]
Outside walls	Curtain wall	Masonry	Brick	Tilt-up	Brick	Concrete	Brick	Metal	Precast	Brick	Block	Block
Number of stories	8	4	6[d]	1	4	4[d]	1	1	8	21	6	2
Location	Va.	Va.	Md.	Mo.	Ohio	Calif.	Texas	Calif.	Ill.	N.Y.	Fla.	Fla.
Cost Items	Percent of Total Construction Costs[e]											
Excavation and site improvements	6.5%	8.6%	4.1%	4.1%	3.8%	3.2%	2.1%	6.0%	1.7%	5.7%	5.5%	6.5%
Foundation, frame, and exterior walls	33.1	26.8	23.9	25.3	24.5	31.7	30.8	[illegible].2[f]	37.0	34.0	25.7	17.5
Interior walls, carpentry, sash and metal lath plus plaster	13.1	17.6	12.3	15.5	14.3	7.7	18.0	12.7	11.4	15.3	19.4	19.4
Plumbing	3.7	7.4	9.3	4.8	6.2	29.6	3.9	10.7	11.2	7.5	9.0	9.5
Heating	11.5	14.3	20.2	13.7	12.1		15.7	5.8	11.3	4.8	7.0	13.3
Electrical	10.4	10.8	9.3	13.0	11.4	14.3	7.7	10.5	7.6	6.6	10.6	12.7
All other[g]	21.7	14.5	20.9	23.6	27.7	13.5	21.8	22.1	19.8	26.1	22.7	19.1
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

a. Engineering News-Record, December 17, 1964, p. 99.
b. Engineering News-Record, September 17, 1964, p. 120.
c. Engineering News-Record, March 19, 1964, p. 109.
d. Plus basement.
e. Contractors overhead and profits are assumed to be included in the various task costs.
f. Includes metal decking.
g. Includes interior finish work, roofing, waterproofing and insulation, mechanical equipment such as elevators, and miscellaneous.

It is important to note that every type of building might not require all of these components, and that deletion of one[1] might not change the cost priority position of the others.

The prospects for savings by incorporating one or more of the above components into an interrelated system are much more difficult to evaluate. (See Section IV.)

Maintenance and/or Operation

In a publication of the Structural Clay Products Institute, authors Grimm and Gross state "In general, the nature of building materials is such that cheapness and true economy may be mutually exclusive. . . . The lowest ultimate cost of a building is, of course, determined by selecting components having the lowest combination of initial cost, maintenance and operation costs."[2]

Maintenance and operation costs for conventionally and mass-produced facilities result indirectly from the quality of materials and methods used in construction. Maintenance-free characteristics of structures and components, fire insurance rates, and utility costs are the main factors. Costs for taxes and some maintenance tasks (such as periodic equipment inspection, grounds maintenance, and watchman services) are not considered since they would be the same regardless of the construction technique.

Maintenance and Utility Costs. These items must be included in discussions of mass production versus conventional construction, but there are so many detailed data (varying across the country) that they cannot be given here.[3] However, overall data show that cumulative expenditures for maintenance can be expected to exceed the initial building cost within 50 to 80 years after construction.[4]

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1. For example, interior walls might be a negligible item in fallout shelter construction, but deletion of this item probably would not affect the relative costs allocated to the shell, heating, electrical, and plumbing components.
2. Grimm, C. T., and J. G. Gross, Ultimate Cost of Building Walls, Structural Clay Products Institute, Jan. 1960, p. 1.
3. See United Nations Economic Commission for Europe, Cost, Repetition, and Maintenance, Related Aspects of Building Prices, 1963, for an extensive discussion of maintenance costs. Also, L. C. Morrow, Maintenance Engineering Handbook, McGraw-Hill, 1957.
4. Ibid., p. 114.

Fire and Liability Insurance. Data on insurance costs, like that for maintenance, vary from building to building and from city to city across the nation. Thus, basic cost data are not presented here and the appropriate reference[1,2,3] for each insurance jurisdiction would have to be used by an experienced insurance adjustor to determine these costs.

Additional Considerations

Useful life, salvage values, and future cost increases are all necessary to consideration of mass production, unless the buildings produced by both conventional and mass-production techniques are identical in every way. Since mass-production techniques reduce the labor component of overall costs, they would appear more attractive if continuing increases in labor cost are anticipated.

Useful Life of Structures and Equipment. Life of structures and equipment change radically, depending on the environment in which they are placed, especially the soil and climate. Thus only generalized data on useful life can be presented. Useful life for many of the newer materials or products of newer construction techniques are not available. See Figure 3 for a general indication of material, structure, and equipment life.

Salvage Values. Cost credits due to salvage values cannot be predicted with certainty. Each evaluation can be made only at the time of retirement. A value prorated on the basis of the estimated useful life remaining at the time of retirement is used for this report. This method is useful only for permanent types of construction or equipment that are retired while still useful for some other purposes.

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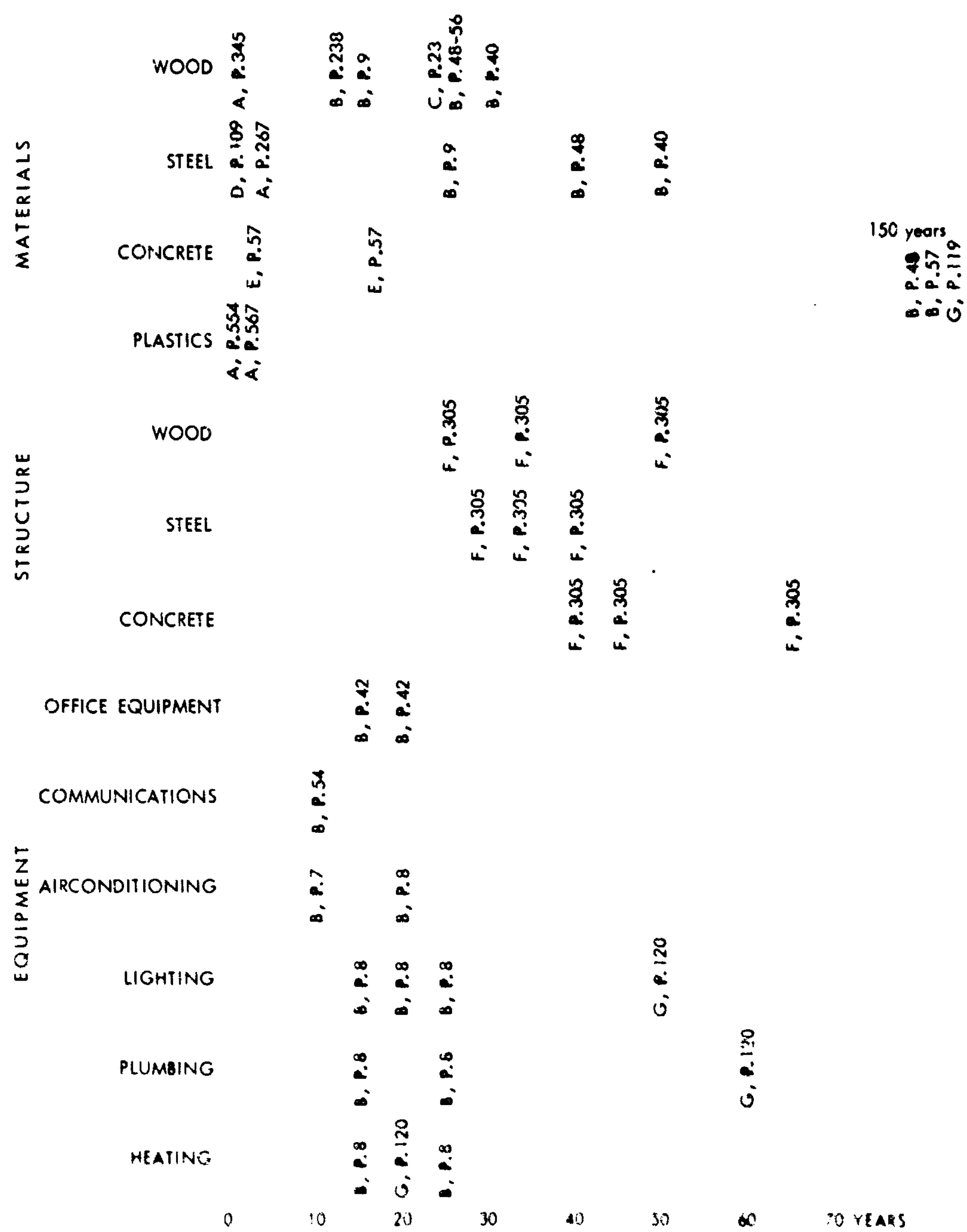
1. Emil Szendy, "How Choice of Construction and Design Details Determine School Fire Insurance Costs," Architectural Record, Jan. 1959, p. 172.
2. National Bureau of Casualty Underwriters, Manual of Liability Insurance, 60 John Street, New York 38, N.Y.
3. There is no standard manual for fire ratings. It is necessary to check specific jurisdictions for schedules applicable in various parts of the country, e.g., Pacific Fire Rating Bureau, New England Fire Rating Bureau, Rocky Mountain Insurance Rating Bureau, Southeastern Fire Underwriters, Western Actuarial Bureau.

Figure 3

SAMPLE LIVES OF MATERIALS, STRUCTURES, AND EQUIPMENT



KEY TO REFERENCES (A, etc. reference, P. page, where these samples are found.)

A. G. A. Greathouse, C. J. Wessel, Deterioration of Materials, Reinhold Pub., 1954.

B. Bulletin "F", Tables of Useful Lives of Depreciable Property, U. S. Internal Revenue Service Publication 173, 1942.

C. Group Shelter Investigation, U. S. Army Engineers Research & Development Labs., Oct. 1962.

D. Engineering News-Record, April 2, 1964.

E. W. E. Grieb, G. Warren, Natural Weathering of Concrete, Public Roads, Vol. 33, No. 4, p. 57.

F. E. H. Boeckh, Boeckh's Manual of Appraisals 4th ed., Rough Notes Co., 1945.

G. Cost, Repetition, and Maintenance, United Nations Economic Commission for Europe, 1963.

NOTE: Sample lives exclude damage by biological agents such as termites, etc.

SOURCE: Stanford Research Institute

Future Increases in Material, Labor, or Equipment Costs. The departments of Labor[1] and Commerce[2] and industry publications[3] compile information on price increases. These references show the following increases over the last 10 years: construction costs, up 5.0 percent per year; foundation, frame, and/or building shell costs, up 3.5 percent per year; skilled and common labor, up 5.0 and 4.0 percent per year, respectively; and materials and equipment costs, up 2.0 percent per year. These are general increases. It would be important, in more detailed studies, also to consider prices for materials or equipment which have decreased.

Shelter Costs Versus Costs for Other Building Types

The objectives of this report would not be attained unless some method is presented to relate the cost experience, discussed earlier, with costs in shelter construction. Since there are no broad data for experience in shelter construction, this relation will be made using the best information available on projected costs for shelters.

The city of Livermore, California, has published projections for a municipally sponsored fallout shelter facility.[4] These projections are used for several reasons. First, they present comprehensive cost data not only for construction but also for items such as financing, engineering design, and maintenance and operation. Secondly, they present projections for a complex of facilities, not simply for a control center or for a single shelter building. Finally, the data appeared sufficiently comprehensive that they could be used with a high level of confidence.

Table 3 shows percentages for projected costs for the Livermore facility together with approximate percentages from Table 2. The cost items are ranked by their contribution to total costs and the ranking shows a similarity between shelters and other types of buildings.

Examples of Total Costs in Shelter Construction

Comparisons of costs for financing, construction, maintenance, etc. require a costing procedure that expresses all costs on an equivalent

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1. U.S. Dept. of Labor, Bureau of Labor Statistics, Consumer Price Index for Selected Items and Groups.
2. U.S. Dept. of Commerce, Business and Defense Services Administration, Construction Review.
3. Engineering News-Record, McGraw-Hill (Construction costs published quarterly.)
4. City of Livermore, Community Shelter Report, Livermore, California, April 1962.

Table 3

A COMPARISON OF CONSTRUCTION COSTS:
Projections for Livermore Shelter Facilities versus
Experience in Construction of Conventional Facilities

Cost Items	Percent of Construction Costs: Livermore Shelter Facilities	Percent of Construction Costs: Conventional Facilities[a]
Excavation and site improvement	5.3%[b]	5.0%
Foundation, frame, and exterior walls	50.1	30.0
Interior walls	2.6[c]	15.0
Plumbing	9.1	8.0
Electrical	10.4	10.0
Heating and ventilating	2.5[d]	12.0
All other (excluding furniture and supplies)	20.0[e]	20.0
Total	100.0%	100.0%

a. Approximate percentages for costs in Table 2.
b. Excavation, backfill, fencing, sidewalks.
c. No lath or plaster included.
d. Ventilation equipment only.
e. These items were not identified in the cost projection for the shelter. It is anticipated that items such as waterproofing, door hardware, roof treatments, and miscellaneous would be about 20% of the total shelter costs as is true of conventional construction. Elimination of this item, however, would not change the cost ranking of the other items.

basis. For the example given here, all costs are expressed in terms of the commonly accepted method of equivalent uniform annual cost, hereafter referred to as annual costs.[1]

The most apparent result of using annual costs is the addition of another dimension to cost expressions commonly employed in construction. That is, instead of making comparisons on the basis of cost per unit for initial construction, this analysis makes comparisons on the basis of costs per unit per year for total costs expected over the life of the facility.

The example places the cost items above into the perspective of total ownership costs, by the annual cost method. The analysis is for the Livermore facility[2] discussed above. Although only estimates are available, the estimates are deemed sufficiently reliable to define the cost relations.

Table 4 shows a breakdown of the total cost. The costs for each numbered phase or item within a phase are described in detail in Appendix A.

The important factors in these calculations are the rate of interest, the useful life, and projected increases in costs for various items. An interest rate of 5.0 percent was used in all calculations for this example, which is evidently the experience of the Livermore municipality. As indicated earlier, this cost usually is closer to 3.2 percent for municipalities across the nation. The difference between 3.5 and 5.0 percent will have very little effect on the cost ranking of items in the total cost structure in Table 4.

Basically, these calculations are for a permanent building that could be used as a shelter for only a portion of its estimated useful life because of obsolescence. Obsolescence would be due principally to the uncertainty in future weapon deployments. That is, instead of present shelter requirements for fallout protection plus some blast protection, weapon types and deployment 10 years hence could generate requirements for a completely different type of building. As a result, a 10-year period to obsolescence as a shelter is used in this example.

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1. For tables for computing annual costs see Minrath, Handbook of Business Mathematics, Van Nostrand, 1959, or F. C. Kent and M. E. Kent, Compound Interest and Annuity Tables, McGraw-Hill, 1926, or Financial Compound Interest and Annuity Tables, Financial Pub. Co., Boston, Mass.
2. Livermore, Community Shelter Report, op. cit.

Table 4

TOTAL COSTS FOR THE LIVERMORE FACILITY

Number	Cost item	Costs (dollars/square foot/year)	
	Administration		
1	Planning management (plus overhead, supervision, legal costs, etc.)	$0.021	
2	Management of maintenance and operations	0.015	
3	Financing	0.281	
	Subtotal		$0.317
	Design		
4	Engineering design		0.039
	Site acquisition (not considered)		
	Construction[a]		
5	Excavation, foundation and building plus miscellaneous	0.144	
6	Ventilating and electrical equipment	0.082	
7	Communication and sanitary equipment	0.117	
	Subtotal		0.343
	Maintenance and operation		
8	Personnel	0.076	
9	Materials, equipment and utilities	0.042	
10	Public liability and fire insurance costs	0.058	
	Subtotal		0.176
	Total		$0.875
11	Supplies, furniture, and miscellaneous		0.173
	Grand total		$1.048

a. Overhead, profit, and contingencies are included in each item.

Planning and design costs are amortized over the 10-year shelter life, since additional costs for these activities would probably be incurred after that time in converting the building to another use. Also, only those costs for the 10-year portion of the building life are charged against the shelter by the use of salvage credits.[1] Costs for permanently installed equipment are determined in the same manner, using the appropriate equipment life. Costs for equipment useful only to the shelter are amortized over the 10-year period.

The effect of these calculations is to charge against the shelter facility only those costs associated with the shelter over a 20-year period. However, the 10-year period actually has no particular significance, since calculations using a 20- and a 30-year period to obsolescence as a shelter show no major shifts in item costs from those for the 10-year period. The main differences are a slight decrease in initial construction costs and a slight increase in maintenance and operating costs.

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1. The salvage value has an important effect on these calculations (see Cost Item 5 of Appendix A), an effect that emphasizes the economic advantage of planning a building that would have a marketable value after it becomes obsolete as a shelter. Since total costs are so sensitive to salvage values, the dual-use aspects of shelters will be one of the more important items to be considered (together with mass-production techniques) in the shelter planning stage.

'Mass production--production of goods in quantity, usually by machinery.'[1]

IV A SURVEY OF MASS-PRODUCTION TECHNIQUES AND COSTS

Mass production in building construction is not a recent development, but involves some terminology that requires an introduction. Mass production for this report refers to factory or machine production, in quantity, of buildings or major components for buildings requiring a minimum of field assembly or erection (e.g., a wall section containing heating elements, electrical fixtures, etc.). This is in contrast to conventional construction practice, where bulk materials (lumber, ready-mixed concrete, etc.) are shipped to the building site for field assembly, largely by hand.

The process of factory assembly also involves design techniques differing from those in conventional construction and results in new terminology. The systems design in this report refers to the design of an integrated system of building components each having more than one function; for example, a heating-lighting system where the proper functioning of the heating component is dependent upon the operation of the lighting component. In conventional design the components generally are not related in form or operation.

The effects of mass production and systems design also extend into management of and specifications for building construction. No special terminology is used in the discussion of management except to refer to the more advanced techniques applicable to both mass production and conventional construction. Most current specifications are material-oriented, in that they often require specific materials to be used in conventional construction. Ideally, however, specifications for mass production would be performance-oriented, so that the systems design and manufacturing processes could make maximum use of new materials and techniques.

The construction industry is currently in the early stages of mass-producing buildings. As a result, numerous examples of mass-production costs, for various items in the total cost picture, appear in the current literature. Since the industry is in the developmental state, it

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1. Webster's New International Dictionary, Second Edition, G & C Merriman Co., Springfield, Mass., 1952.

is not possible, in a preliminary survey, to determine exact overall differences in the total cost of buildings using mass-production versus conventional techniques. However, the examples below illustrate techniques and costs for the more important items identified in Section III; from these the overall potential may be evaluated.

The contracting environment of building codes and labor union practices, and the characteristics of slow industrial change would require some revision before all of the techniques mentioned here as examples could be used in this country. Most of the techniques, however, are currently being, or have been, used. The examples deal primarily with the planning, design, research and development, and construction phases.

Several factors indicate the potential of mass-production techniques in construction--industry acceptance and use of various new techniques in current construction, and continuing research and development efforts on particular techniques. These factors are included in the discussion of examples when appropriate.

Examples of Mass-Production Techniques in Building Construction

Management Techniques

The importance of these techniques is not that they are large cost items, but rather that they are essential to the full derivation of benefits from mass-production methods.

A widely discussed school development project[1] in California provides one of the more sophisticated examples of building planning. This project is sponsored by the Educational Facilities Laboratories, The Ford Foundation, and 13 California school districts. Its major contribution is in the use of a set of written performance specifications. Basically, the scheme consisted in studying requirements (in this case, school activities) for the completed facilities, and in writing performance specifications for the facility to meet those requirements. There is nothing unusual about the use of performance specificiations, especially by architects. It is, however, very unusual in current construction practice to write performance specifications for use by materials and equipment suppliers.

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1. See B. P. Spring, "School Costs Cut by New Components," Architectural Forum, Feb. 1964.

This planning technique resulted in specifications for manufactured components of conventional construction that would fit together as effectively and inexpensively as possible. Note that this was a planning and specification writing activity, and not a design activity.

The Building Research Advisory Board[1] has listed a number of problems that the use of performance specifications may solve:

1. Inadequate methods that are currently used for selecting and specifying building components.

2. Inadequate methods for relating the performance of all parts of a building.

3. Costly and time-consuming testing methods and procedures that are used to predict performance levels.

4. Delayed approval and acceptance of innovations in building.

Although compatible in form, the components, designed by industry from the performance specifications, are not interrelated in function. This characteristic is true of most conventional construction. The price advantage lies in their working well together and in their being mass produced.

The degree of success in planning by management is shown by the fact that price bids for the components came in at about 18 percent less[2] than for similar components in conventional construction. It is possible that these savings might not accrue to clients other than the original 13 California school districts, since the manufacturers absorbed research and development costs that could increase the price of future sales.

Management scheduling or control techniques are also important for their advantages to management in project planning and control of time schedules, costs, and quality.[3,4] It is the change in management costs

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1. "Will Performance Specs Work?", Engineering News-Record, March 4, 1965, p. 21.
2. B. P. Spring, op. cit., p. 112.
3. DOD and NASA have also suggested the use of a management technique for cost accounting via PERT/COST GUIDE.
4. J. L. Halcomb, "The Use of PERT in Product Design," American Society of Mechanical Engineers, Paper No. 63-MD-13, March 1964.

and the overall savings generated by these techniques in mass production that are pertinent to this study. The difference between these techniques and those for the school development project above is that these techniques represent attempts to derive the maximum usefulness from personnel and resources rather than from manufactured building components.

There are so many different scheduling programs suggested in current literature that the choice of the most advantageous is the main problem. Critical Path Method (CPM), Program Evaluation Review Technique (PERT), PERT/COST, and Resource Allocation and Multi-Project Scheduling (RAMPS) are but a few of the more familiar methods that could be used in construction.

Cost differences in management with and without scheduling techniques are probably impossible to compile. Costs of implementation of the techniques are available, but costs of the replaced management functions are not.

Available data show that the lack of skill in the use of these techniques can result in costs that are about double[1] those for skilled implementation. Also, cost for skilled implementation varies from about 1.0 percent of projects costing about $5 million down to about 0.2 percent of projects costing $100 million or more.[1]

Architectural and Engineering Design

The engineering design technique that would result in the greatest cost difference between conventional and mass-produced buildings is the systems approach or concept.[2,3,4] Clive Entwhistle, Design Consultant, says,"Important breakthroughs in building economics will not be made by mass-producing components, but by the development of systems that permit a rational assembly of elements into integrated wholes and sub-wholes."[5]

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1. B. O. Szuprowicz, "Choosing a Critical-Path Scheduling Program," Engineering News-Record, June 18, 1964, p. 79.
2. William Arrott, "Systems Engineering Approaches the Threshold of Maturity," Electrical Manufacturing, May 1960, p. 161.
3. W. R. Hilliard, "Use of Systems Engineering to Reduce Costs," Tappi, Aug. 1963, p. 169A.
4. A. D. Hall, A Methodology for Systems Engineering, Van Nostrand, 1962.
5. Clive Entwhistle, Design Consultant, Progressive Architecture, October 1964, p. 222.

Carl Koch and Associates add, " . . . larger assemblies of components represent only part of the answer: . . . integrated systems of components are required if significant benefits are to accrue."[1]

Costs for employment of the systems concept in management and design can be expected to exceed those for conventional techniques, particularly in the early stages of development or for the first in a series of projects.[2]

Architect and engineering design fees suggested by the AIA are for conventional construction. These fees could be expected to rise substantially for the more promising systems designs for mass-produced buildings. Suggested fees for detailed designs are as high as 15 percent[3] of the construction costs.

Systems design tasks would fall upon both the architect and the engineer if this approach were used. This is due to the emphasis in systems design on the interrelation between functions in building such as between the structure and the heating or cooling components or between the heating and lighting components. A general list of such functions for a shelter facility would include, among others, a radiation shield, a shell for protection from weather or environment and for support of the shield, a lighting function, a sanitation function, a ventilation function, and a water supply or storage function. Under the systems concept, as many of these functions would be interrelated as possible. Currently only a few of these functions have been systematized but the cost savings of the successful systems are promising. One of these is a heat-cooling-lignt system.

The heat-cooling-light system[4] is one which utilizes heat from the sun, lights, occupants, and electrical equipment to provide for varying heating levels. Incorporated in the system is an underground tank for storage of either heated or chilled water, electric resistance heating, and a heat exchanger which preheats incoming air with heat extracted from the flow of exhaust air. The use of available heat sources reduces heating requirements to the extent that the electrical unit is used for only 2 percent of the heating season.

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1. Ibid, p. 221.
2. For a methodology using the systems concept, see C. J. Hitch and R. N. McKean, The Economics of Defense in the Nuclear Age, Cambridge, Mass.: Harvard University Press, 1960.
3. California Council of the AIA, op. cit.
4. W. J. McGuinuess, "Heat-by-Light," Progressive Architecture, Nov. 1964, p. 208.

The heat-by-light design was a collaborative achievement between an architect, an electronic company plant engineer, and a consulting engineer. The installation operates, during the heating cycle, for a fraction of other fuel costs.[1] Research and development and capital investment costs were not available to this study. This design and similar systems have been developed by Thomas Beens, Consulting Engineers, as well as by Meckler-Hoentz and Associates of Toledo, Ohio.[2]

Other system proposals and developments have combined: the structural and heating functions so that the structure acts as a distributor and/or radiator; the building shell and heating systems so that the facade acts as a heat-sink or source for the cooling and heating system; and the structure and water storage functions so that the shell or frame also forms a reservoir for water storage. These are merely examples of component combinations into systems to show the range of possibilities rather than the cost advantage of each.

Costs for Research and Development

R&D costs in the School Construction project were borne entirely by the manufacturers bidding for the contract to the 13 school districts. Only estimates of such costs are available in the literature.

In all, an estimated \$2 million[3] or 13 percent was spent on research, design, and development costs for components to be used in an estimated \$30 million[4] building volume.

Several of the successful bidders however, are currently making large capital investments in manufacturing facilities for their products, indicating that the R&D costs will eventually be apportioned to a much larger sales volume than the initial \$15 million breakeven point.[4]

It is important to note that these R&D costs were not expended on systems development, but on a scheme for making currently developed

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1. Ibid., p. 208.
2. "Lower Cooling, Lighting Costs Foreseen," Engineering News-Record, April 30, 1964, p. 21.
3. B. P. Spring, op. cit., p. 113.
4. Educational Facilities Laboratories, SCSD, an Interim Report, New York, New York, Feb. 1965, p. 8.

components fit into a highly compatible group.[1] Development of wholly new systems could be expected to cost substantially more than development for this scheme. The advantage of the scheme is that it generated cost savings in a semi-mass-produced type of construction acceptable to the construction environment (e.g., building codes, labor unions, contractors).

Construction Techniques and Costs

It is in the construction phase that the most important cost differences between conventional and mass-production methods will arise. It is also the phase in which most of the cost shifting will occur, not only between tasks within the phase, but also between this phase and the project management and/or engineering design phases.

Costs for labor, materials, equipment, and methods of construction can vary widely for different techniques. However, those for overhead, profit, and contingencies (although equally important because they represent so large a portion of construction costs) would not be expected to vary due to the adoption of new techniques, and are not included in the following discussion.

It is also within the construction phase that mass-production techniques would have to generate the largest savings, both to offset possible cost disadvantages in the management and engineering design phases and to provide overall cost advantages, of any, over conventional techniques.

Research and development for new materials could be expected to have a greater impact on mass production than they currently do on conventional techniques. New plastics,[2] ceramics, steels,[3] and modified materials such

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1. The process of more effective fitting of conventional components is referred to as a "scheme," since, although they are highly compatible in placement and support, the components are not dependent on one another for performance of their intended function. The systems referred to earlier do depend on each other for their successful operation.
2. A new vinyl concrete for surfacing and waterproofing wood, concrete, metal, tile, etc., is produced by Aqua-Dri and developed by Silcoa Products of N.Y., N.Y.
3. V. F. Zackey, "The Strength of Steel," *Scientific American*, Aug. 1963, p. 72.

as the expanding cements,[1] and wood plastics[2] generally find more rapid acceptance in manufacturing than in conventional construction.

It was shown earlier that maintenance costs were directly associated with initial construction methods and materials. Accordingly, mass-production techniques that have an impact on both construction and maintenance costs have been included in this discussion.

Finally, it should be noted that the history of the changes in construction techniques reveals an evolutionary process of incorporating elements of mass-production procedures into the construction process. The Bureau of Labor Statistics bulletins comment on this effect: " . . . a very rough estimate for price change indicates that total man-hours per $1,000 (in constant prices) of school construction have declined by approximately one-third in the past 20 years, with a greater decline occurring for on-site employment than for off-site employment."[3] Also, " . . . on-site man-hours per $1,000 (in constant prices) of Federal building construction have declined by approximately one-sixth in the past 20 years."[4]

Note that the one-sixth decline was for on-site man-hours, and the one-third decline of the previous quotation for total man-hours. This general decline is attributed to increased productiveness through mechanization, a transfer of on-site tasks to shops, and finally, to changes in materials and methods. The indications are, therefore, that construction methods are changing in such a way that on-site labor requirements are in a decline. There are no strong indications that this decline is slowing and a number of indications (see Production Costs, following) that the decline will continue, due in a large part to the growing employment of labor-saving and mass-production techniques.

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1. "Expanding Cement Prevents Roof Cracks," Engineering News-Record, Jan. 16, 1964, p. 32.
2. The AEC plans to let a $60,000 contract for the design of a pilot plant to produce American Novawood Corporation's plastic impregnated wood development. This material evidently has all the advantages of both wood and plastic making it highly desirable for numerous uses. Fortune, Feb. 1965, p. 209.
3. Bureau of Labor Statistics, Bulletin 1299, op. cit., p. 9.
4. Bureau of Labor Statistics, Bulletin 1331, op. cit., p. 9.

Capital Investment Costs. An example of the time required to amortize the initial investment in mass-production facilities is given by E. T. Shiffer, writing about mass-production construction in France:

"The decisive moment for success of the system came in 1952 when the French government, anxious to develop new methods of cost and labor saving construction, selected the Camus Company to build 4,000 flats . . . A permanent factory was built to produce these flats. In the two-year span of this project, the factory was almost completely amortized."[1]

A general indication of the capital investment required for similar concrete fabricating plants is given by Shiffer for a Danish facility with a capacity to mass-produce 2,000 multi-unit apartments per year. Initial costs for this facility were approximately $1 million in 1960.[2]

Production Costs. Production cost data are generally available. These costs are often presented in terms of savings over conventionally constructed items with little or no reference to capital investment or setup costs.

J. H. Perlmutter, in a journal of the concrete industry, writes of this problem:

"The most significant direction of mechanization, however, in terms of dollar savings in labor cost and dollar volume of goods produced is in the concrete placement process . . . the unit labor cost of . . . machine-made material may be half that of producing conventional double tee slabs. Naturally, until the machines are amortized, the saving in labor is diverted to paying for the capital goods."[3]

The above comments concerning construction with concrete are substantiated in a number of sources.[4] The costs of standard forms, for example, versus the number of times that the form is used, is shown in Figure 4. According to the figure, form costs could not be expected to

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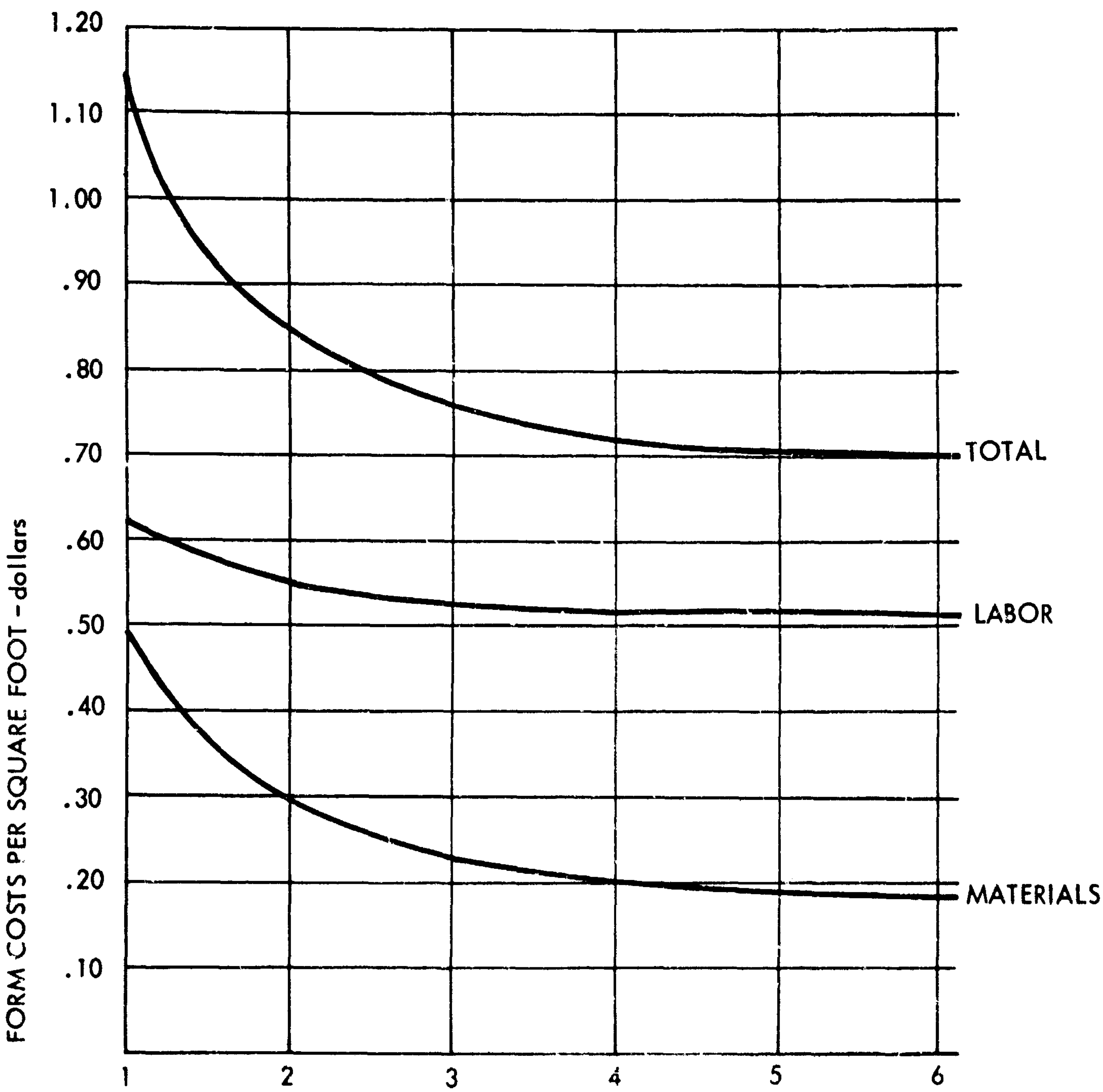
1. E. T. Shiffer, "Industrialized Building, Western Europe," Progressive Architecture, Oct. 1964, p. 196.
2. Ibid., p. 199.
3. J. H. Perlmutter, "Machines in Place of Forms," Journal of the Prestressed Concrete Institute, August 1964, p. 17.
4. U.N. Economic Commission for Europe, Cost Repetition Maintenance, Geneva, 1963.

Figure 4

FORM COSTS IN CONCRETE CONSTRUCTION VERSUS REPETITIONS OF USE



NUMBER OF TIMES FORM IS USED

NOTE: After the fifth use of wood forms, requirements for new materials prevent further price reduction.

SOURCE: R. S. Means Engineers and Associates, op. cit., p. 25

drop much lower than about $0.70/sq ft in conventional construction. If, however, the comments made by Mr. Perlmutter (e.g., the reduction in labor costs through mass production without forms) also applied to general building construction, casting costs might drop as low as $0.30 to $0.40/sq ft. These lower costs would, of course, be contingent on the successful amortization of capital investment costs.

The success of mass-production techniques for concrete placement without forms is pointed out by the extensive use of machines in concrete fabrication plants both in this country and abroad. In Russia, where the largest capital investments and most advanced development of factory production of concrete have been made, concrete fabricating plants rival the size of some of our intermediate sized steel-fabricating and ship-building facilities.[1] This is an interesting comparison in itself, and is perhaps indicative of the future of the mushrooming[2] concrete fabricating industry in this country.

Mass production of components using wood, steel, aluminum, and clay blocks has not been as successful as that using concrete. A survey of European techniques[3] shows some of the earlier attempts for fabricating components using wood as the basic material. These techniques have been recently revived in response to the U.S. Army request for transportable facilities to be erected overseas. This project however was stimulated by attempts to improve this country's balance of payments rather than by economic considerations in building.[4]

Steel and aluminum housing components have a history similar to that of wood components and except for facade panels, are not widely employed in current construction.

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1. Prof. V. V. Mikhailov, "Recent Developments in the Automatic Manufacture of Prestressed Members in the USSR," Journal of the Prestressed Concrete Institute, Sept. 1961, p. 34.
   Prof. V. V. Mikhailov and A. A. Susnikov, "Development of Factory Production of Precast Prestressed Concrete in the USSR," Journal of the Prestressed Concrete Institute, April 1963, p. 48.
2. The industry association, Prestressed Concrete Institute, has grown from 0 to 200 manufacturing company members in 10 years. The first seminar on prestressing was held at M.I.T. in 1950, and that meeting initiated the first use of the technique in this country.
3. Organization for European Economic Cooperation, Prefabricated Building, Paris, France, Dec. 1958.
4. Engineering News-Record, Feb. 18, 1963, p. 6.

Other costs of interest to this discussion are setup costs, that is, the costs for adjusting manufacturing equipment to produce a specific item. These costs are often referenced to the breakeven number, that number of units which must be produced to warrant equipment adjustments.

The more rapidly amortized setup costs require the production of as few as 200 elements[1] for simple building components. More slowly amortized setup costs are encountered in the production of architectural facades, where 5,000 units[2] of production are required to recoup setup expense and a reasonable profit.

Erection. The emphasis, during the manufacturing stage, is on the production of as complete a product as possible. Transportation to the site and erection are thereby minimized for the more successful projects. On-site costs can be further reduced with development of prefabricated foundations.[3] Extreme examples of minimal on-site requirements for labor and time include the erection of a 40-family, 5-story dwelling in 24 days.[4] The erection activities are being increasingly speeded by the employment of new and more specialized equipment such as tower cranes, climbing cranes, and mobile or self-powered equipment.

An OEEC publication, Prefabricated Building, discusses labor requirements for erection:

"A second example, that of prefabrication at Evreux, France, shows that only 25 percent of the total man-hour requirements were spent on the building site. The percentage of skilled workers needed could be reduced from 50 to 16 percent."[5]

As for transportation, Mr. Shiffer comments: "The French systems consider a 40 to 60 mile range as the economic maximum shipment range, although Larsen and Nielsen in Copenhagen has made and shipped, by truck and water, a housing project to Hamburg, Germany, a distance of 195 miles.[6]

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1. E. T. Shiffer, op. cit., p. 200
2. Conversations with Mr. L. Dreon of the Grassi-American Corporation, Precast Concrete Products Division, South San Francisco, California.
3. U.N. Economic Commission for Europe, op. cit., p. 149
4. E. T. Shiffer, op. cit., p. 198
5. OEEC, Prefabricated Building, European Productivity Agency, Paris, 1958, p. 115.
6. E. T. Shiffer op. cit., p. 196.

This relatively long-distance transportation in construction, coupled with the growing number of concrete and steel fabricating plants, could place most of the U.S. population within shipping range of mass-produced building components.

Evaluation of Changes in Total Cost

Data, primarily from European experience, indicate a cost saving potential for mass production in building construction, even though the survey could not include a detailed cost analysis. Shiffer found that: "Coignet does the entire project, including site work. They report savings of . . . around 10 percent over traditional construction."[1] Similarly, the use of another French system for 29,000 flats (either constructed or in the planning stage) shows " . . . 20 percent less labor than conventional construction, . . . 8-10 percent less time, and costs 5-8 percent less,"[1] It is important to note that it can be said of these techniques that, "In the past 10 years, . . . only a small step has actually been taken in the direction of industrialization."[2] This indicates that even larger savings might be possible, since the full potential of mass production has not yet been explored.

These general savings are substantiated by results in specific projects such as at Evreux, France, where " . . . the quality of the work was unquestionably higher than the standards of other similar operations . . . 40 flats built on 5 floors . . . required only 40 days to complete after the basement had been finished, . . . and building costs were approximately 10 percent less than for a conventional one of corresponding type."[3] In Brussels, a project " . . . which was designed for conventional *in-situ* concrete, the contractor proposed the Barets system and actually cut the cost by 4 percent."[4]

Smaller steps toward mass production in the U.S. have produced the same results, i.e., "the newly developed components for structure and integrated ceilings plus air conditioning and partitions . . . [cost] $1.50 per square foot less than the same elements in a conventionally built school--a savings of 18.4 percent."[5] This technique was so promising

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1. E. T. Shiffer, *op. cit.*, p. 198.
2. *Ibid.*, p. 200.
3. OEEC, *op. cit.*, p. 117.
4. E. T. Shiffer, *op. cit.*, p. 198.
5. B. P. Spring, *op. cit.*, p. 112.

that architects Skidmore, Owings, and Merrill were asked to study the feasibility of incorporating it into a $130 million project for the state of New York.[1]

Since the use of this technique tends to lower component and erection costs, the savings appear to substantiate conclusions of the very large study by the secretariat of the Economic Commission for Europe, " . . . major economies in building costs can be achieved through a serious effort to reduce the cost and/or quantity of materials, either on the site or at the factory," and "the cost of construction . . . [using large components] is in some cases substantially lower--from 10 to 20 percent--than the cost of traditional construction. In all countries . . . the technique has considerably reduced the number of man-hours on site, and sometimes . . . total man-hours."[2] Mr. Vortman suggests that even larger savings are possible in shelter construction simply by standardizing components and purchasing in quantity.[3]

Figure 5 shows cost changes identified in the survey. Each cost item is shown with an area that approximates its contribution to the total cost, and with a direction and magnitude of expected cost changes. Many of the changes are cost shifts rather than differences; it is not possible to show a change in the total cost until a detailed study provides data on items with question marks also shown on the figure.

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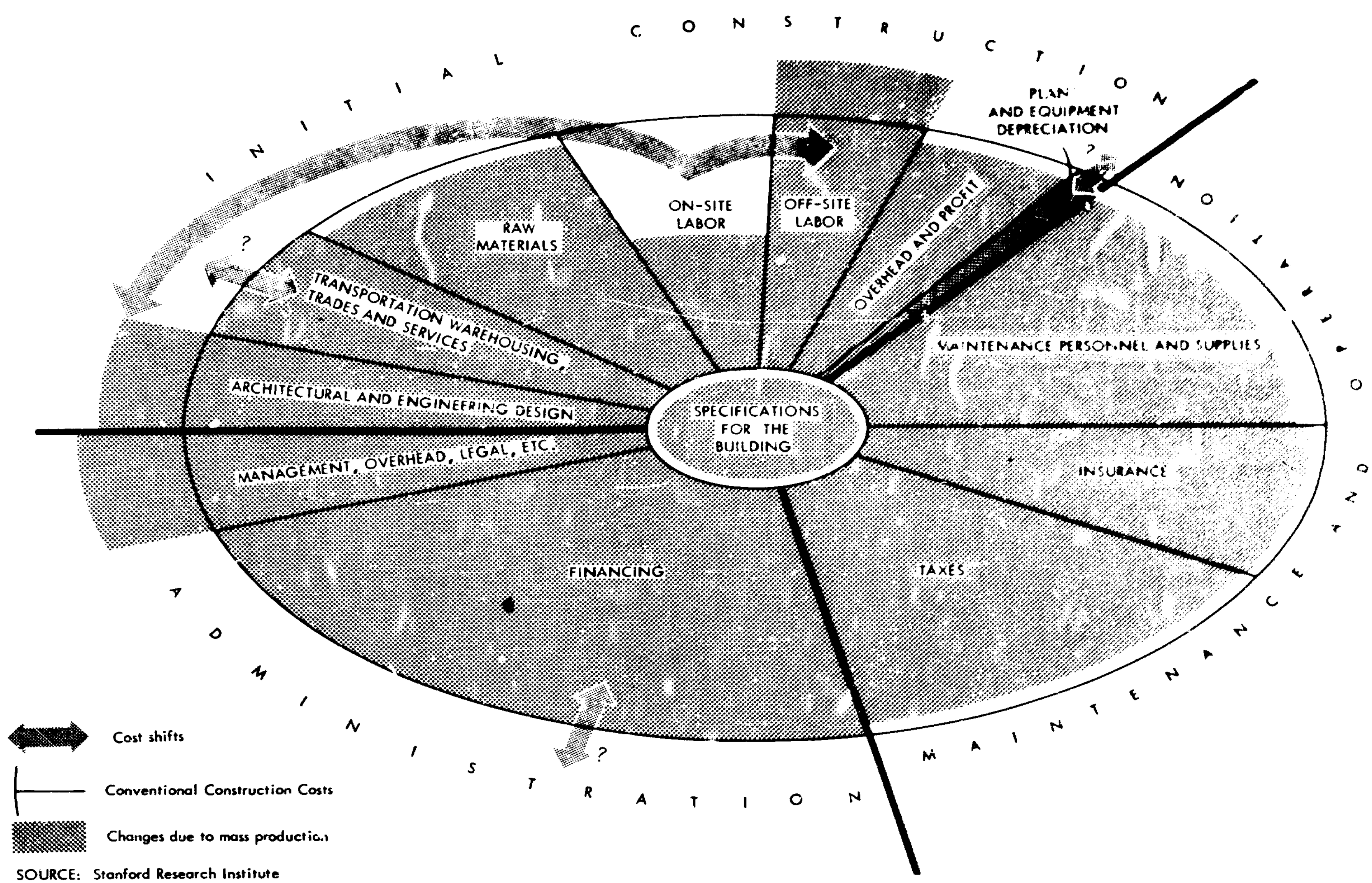
1. Engineering News-Record, January 14, 1965, p. 21.
2. United Nations Economic Commission for Europe, op. cit., p. 19.
3. L. J. Vortman, A Comprehensive Shelter Program, Project Harbor, National Academy of Sciences, National Research Council, 1964, p. 18.

Figure 5

CHANGES IN THE TOTAL COST STRUCTURE FOR CONVENTIONAL CONSTRUCTION VERSUS MASS PRODUCTION



SOURCE: Stanford Research Institute

Appendix A

EXAMPLE COST CALCULATIONS

The cost calculations below are for the example in Table 4 which is repeated at the end of this Appendix so it may be unfolded for reference while reading the Appendix. End-of-the-year accounting factors are used to convert all costs to equivalent uniform annual costs.

Land acquisition was not considered in the Livermore study, but it would undoubtedly be a factor for many municipalities, and particularly for metropolitan areas where school grounds are not large enough to contain shelter buildings.

Cost Item No. 1

These costs are amortized over the 10-year period.

Planning costs of about 2 percent of the initial construction costs were derived from data on a large school development project.[1] Thus, 2 percent of these costs totaling $7.900/sq ft in Table A-1 is $0.158/sq ft. This cost, allocated over a 10-year period at 5 percent interest (using a capital recovery factor of 0.1295) is $0.021/sq ft/yr.

Cost Item No. 2

Management costs for supervision of maintenance and operations are, for lack of data, estimated to be one-tenth of yearly maintenance and operating costs, excluding insurance. Thus, a constant wage or salary level would generate costs of (1/10) ($0.118, cost items nos. 8 and 9 in Table 4), or $0.012/sq ft/yr. A salary scale increasing at a rate of about 5 percent[2] per year would add equivalent uniform annual costs of about $0.003/sq ft/yr for a total of $0.015/sq ft/yr.

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1. See "Planning and Operations Management," Section III.
2. This rate of increase is considered to be the same as that for skilled labor.

Cost Item No. 3

Financing for this facility would be by bonds to be repaid through assessment district proceedings.[1] The important factor here is not so much how it is repaid, but when and at what interest rate.

One alternative for this facility would be annual repayments over 10 years at 5 percent interest. The uniform annual interest on the principal divided by the shelter area is $0.281/sq ft/yr. The 10-year repayment schedule coincides with the useful facility life used in this analysis, therefore the $0.281 annual cost is directly applicable without further modification.

Cost Item No. 4

The Livermore study recognizes a 4 percent cost[2] for engineering design, but nothing for architectural design or construction supervision by the architect. Avoidance of an architect's fee for supervision is deemed feasible, but payment of the architectural design fee by most municipalities is customary. A minimum fee[3] for repetitive-type warehouses is 6 percent, which would include both the architectural and engineering costs. However, the 4 percent rate is used in this example for consistency with the Livermore data.

Four percent of the estimated $7.596/sq ft for building and equipment costs in Table A-1 is $0.304/sq ft, and apportioned over the 10-year period, is (0.1295) ($0.304/sq ft) or $0.039/sq ft/yr. The entire engineering design cost is written off over the 10-year period.

Cost Item No. 5

Excavation and building costs of $5.550/sq ft are for both the shelter area and for the control center. They include overhead, profit, materials, and labor.

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1. City of Livermore, op. cit., p. 65.
2. City of Livermore, op. cit., p. 41.
3. California Council of AIA, op. cit.

Table A-1

DETAILED COSTS[a] FOR THE LIVERMORE[b] FACILITY
Shelter for 22,800 Persons at 12 Square Feet per Person
Shelter Area 273,600 Square Feet
Total Initial[c] Cost, about $2,442,000

Item[d]	Shelter Building	+ Control Center	Total Cost	Cost per Square Foot
Construction				
Excavation + building	(197,424)(7.6) +	17,965 =	$1,518,519	$5.550
Electrical	(32,160)(7.6) +	4,680 =	249,267	0.911
Ventilation	(8,308)(7.6) +	477 =	63,618	0.233
Plumbing + water + drains	(30,171)(7.6) +	1,873 =	231,173	0.845
Communication	(1,715)(7.6) +	2,626 =	15,660	0.057
Building and equipment costs				$7.596
Engineering design	(0.04)(7.596)			0.304
Initial construction costs				$7.900
Furniture, supplies, + miscellaneous	(117,640)(7.6) +	29,560 =	363,906	1.330
Total initial costs				$9.230
Uniform annual interest on $2,442,000 at 5% for 10 years		=	76,788	0.281
Maintenance personnel cost		=	16,788	0.062
Maintenance supplies, equipment, and utilities cost		=	10,302	0.038

a. Based on 1962 prices. Item costs include overhead and profit.
b. City of Livermore, op. cit., pages 36-42.
c. Excluding engineering, but including cost of federally donated supplies.
d. Including control center.

The method for allocating the costs of the concrete structure (which, on the basis of data in Figure 3, is estimated to have at least a 50-year life) is as follows:

After only ten years, the structure will still have 40 years of usefulness for some other purpose, e.g., warehousing, records storage, recreation activities, etc. Therefore salvage credits would lower shelter costs over the 10-year period.

The $5.550/sq ft cost is apportioned over ten years as follows: ($5.550/sq ft) (0.1295, the capital recovery factor for 5 percent over 10 years) equals $0.718 sq ft/yr. From this must be subtracted salvage credits.

A 5 percent rise[1] per annum in construction costs would mean that the same facility, 10 years later, would cost ($5.550/sq ft) (1.629, the compound amount factor for 5 percent per year over 10 years) or $9.040/sq ft. Since four-fifths of the life of the structure would remain at that time, the salvage value would be (4/5) ($9.040/sq ft) or $7.220/sq ft.[2] This value, spread over the previous 10-year period, would be ($7.220/sq ft) (0.0795, the sinking fund factor for 5 percent over 10 years) or $0.574/sq ft/yr.

The cost of the building for shelter purposes, then, is $0.718-$0.574, or $0.144/sq ft/yr.

Cost Item No. 6

Costs for ventilation and electrical equipment are treated in the same manner as costs for buildings except that the useful life of such equipment is estimated to be 25[3] instead of 50 years.

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1. See "Future Increases in Costs," Section III.
2. Actual salvage values cannot be predicted. The sale of a shelter (when it is no longer useful for that purpose) would depend on many factors. Calculation of a salvage credit by a proportion of the remaining life of the building is deemed reasonable since, in effect, this method does not charge the prospective new owner for land, and other initial costs such as management and architectural or engineering design. It is important to note that the salvage value has a large effect on the cost of the building, and emphasizes the economic advantage of planning a shelter building that would have a marketable value after it becomes obsolete as a shelter.
3. See Figure 3.

Total electrical plus ventilation costs equal $1.144, and over 10 years at 5 percent, $0.148/sq ft/yr.

Equipment costs rise 2 percent per year[1] and only three-fifths of the equipment value would remain after 10 years. Salvage credits, therefore, are (3/5) ($1.144 sq ft) (1.219, the compound amount factor for a 2 percent rise per year over 10 years), or $0.836/sq ft. This credit over the previous 10 years is ($0.836/sq ft) (0.0795, the sinking fund factor for 5 percent over 10 years), or $0.066/sq ft/yr.

Electrical and ventilating costs for shelter costs, therefore, are $0.148-$0.066, or $0.082/sq ft/yr.

Cost Item No. 7

Costs for communication and sanitary equipment are specialized for the shelter, therefore they are fully amortized over the 10-year period. These costs, from Table A-1, are about $0.902/sq ft, and over 10 years at 5 percent, equal $0.117/sq ft/yr.

Cost Item No. 8

Personnel costs for maintenance and operations are $0.062/sq ft for the first year. Using a 4 percent wage increase per year, these costs would be increased by $0.014 for a total of $0.076/sq ft/yr.

Cost Item No. 9

Materials, equipment, and utility costs were estimated at $0.038/sq ft for the first year. With an increase of 2 percent per year for these costs, the total would be $0.038 plus $0.004 or $0.042/sq ft/yr.

Cost Item No. 10

Insurance costs were not included in the Livermore report since they cannot be estimated until the use of the facility is determined; such

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1. See "Future Increases in Costs," Section III.

costs could vary from the actual computed costs by factors of 2 or 3. Because of these factors, only a very rough estimate of such costs was made by the following method: the current composite fire insurance rate for all the public buildings in Livermore is applied to the total initial costs plus contents; no increase in insurance rates is calculated.

At a rate of \$0.177/\$100.00[1] valuation, annual fire insurance costs for the entire facility would be \$0.016/sq ft/yr.

The city of Livermore is currently paying annual public liability premiums[2] of \$2,500 to \$3,000 on about \$550,000 of total building worth.[3] If the same general rate was applicable to the shelter facility, public liability insurance costs for that facility would be (\$2,500/\$550,000/yr) (\$9.230/sq ft from Table A-1), or \$0.042/sq ft/yr. This is only an estimate.

Total insurance costs by this method are \$0.058/sq ft/yr.

Cost Item No. 11

Furniture, supplies, and miscellaneous shelter equipment costing \$1.330/sq ft are written off over the 10-year period to retirement. Thus, this cost is \$0.173/sq ft/yr.

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1. Determined from conversations with Mr. W. Parness, City Manager, and Mr. James Kennedy, Finance Office, for the city of Livermore.
2. Excluding automotive liability costs.
3. Estimated cost of the facility in 1962.

Table 4

TOTAL COSTS FOR THE LIVERMORE FACILITY

Number	Cost Item	Costs (dollars/square foot/year)	
	Administration		
1	Planning management (plus overhead, supervision, legal costs, etc.)	$0.021	
2	Management of maintenance and operations	0.015	
3	Financing	0.281	
	Subtotal		$0.317
	Design		
4	Engineering design		0.039
	Site acquisition (not considered)		
	Construction[a]		
5	Excavation, foundation and building plus miscellaneous	0.144	
6	Ventilating and electrical equipment	0.082	
7	Communication and sanitary equipment	0.117	
	Subtotal		0.343
	Maintenance and operation		
8	Personnel	0.076	
9	Materials, equipment and utilities	0.042	
10	Public liability and fire insurance costs	0.058	
	Subtotal		0.176
	Total		$0.875
11	Supplies, furniture, and miscellaneous		0.173
	Grand total		$1.048

a. Overhead, profit, and contingencies are included in each item.

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13. ABSTRACT

This report presents the results of a survey, the object of which was a preliminary determination of the potential of mass production for lowering shelter costs.

All cost items necessary to a comparison of mass production versus conventional techniques in building are identified. These cost items, for a conventionally built shelter, are arrayed for identification of those for which significant savings through mass production are possible.

Selected items whose cost may be reduced through the use of mass-production techniques, are reviewed and savings estimated. Finally the direction of future research, to quantify the savings identified in the preliminary survey, is outlined.

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